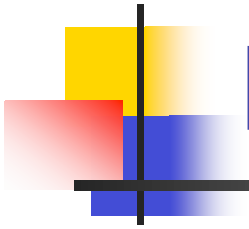
The Top Quark Discovery: From a CDF Viewpoint

Kirsten Tollefson

Michigan State University

Hadron Collider Physics Summer School

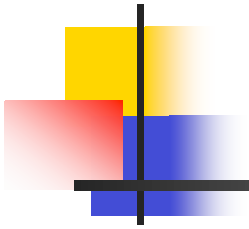
August 9-18th, 2006



My Background

- Graduate student with University of Rochester from 1992-97.
- Worked in b-tagging and L+jet groups, thesis result was Run I L+jets top mass
- Lots of work done by lots of people, these are just my recollections

A Simplified History of the Quark Model



- 1964 - Gell-Mann, Zweig - idea for 3 quarks - up, down, strange (u, d, s)
- 1970 - Glashow, Iliopoulos and Maiani - 4 quarks - up, down, strange, charm (u, d, s, c)
- 1973 - Kobayashi and Maskawa - add 2 quarks top and bottom (t, b) to explain CP violation
- 1974 - Ting, Richter discover charm
- 1977 - Lederman (Fermilab) discovers bottom
- B weak isospin = -1/2, need +1/2 partner

There must be a Top!

Top Mass Predictions and Discovery

- Several top mass predictions in late 70s
  - Predict $5 < M_{top} < 65$ GeV
  - Rule of 3

s	c	b	t	Quark
0.5	1.5	4.5	15	Mass (GeV)

- Jan. 1983 UA1 & UA1 discover W boson
- May 1983 UA1 discovers Z boson
- June-July 1984 Rubbia discovers Top!
  - Articles (*Nature, NY Times*) and press release
  - Mass peak between 30-50 GeV

(See J. Womersley's talk on Wednesday for more details)

Meanwhile back at Fermilab

- 1977 - First discussions of colliding p-pbar beams at Fermilab and a detector
- 1981 - CDF Design Report - general purpose detector with magnetic field
- Oct. ‘85 - CDF sees first p-pbar collisions - collect total 23 events
- Run 0 - June ‘88 - May ‘89, collect < 5 pb^{-1}
  - Set limits on M_{top} > 91 GeV using Dilepton and L+jets channels (first use of SLT tagging)
  - Mass too high for CERN, Fermilab only game in town

A Quick Review on Top Production and Decay

- Top pair production via the strong interaction:

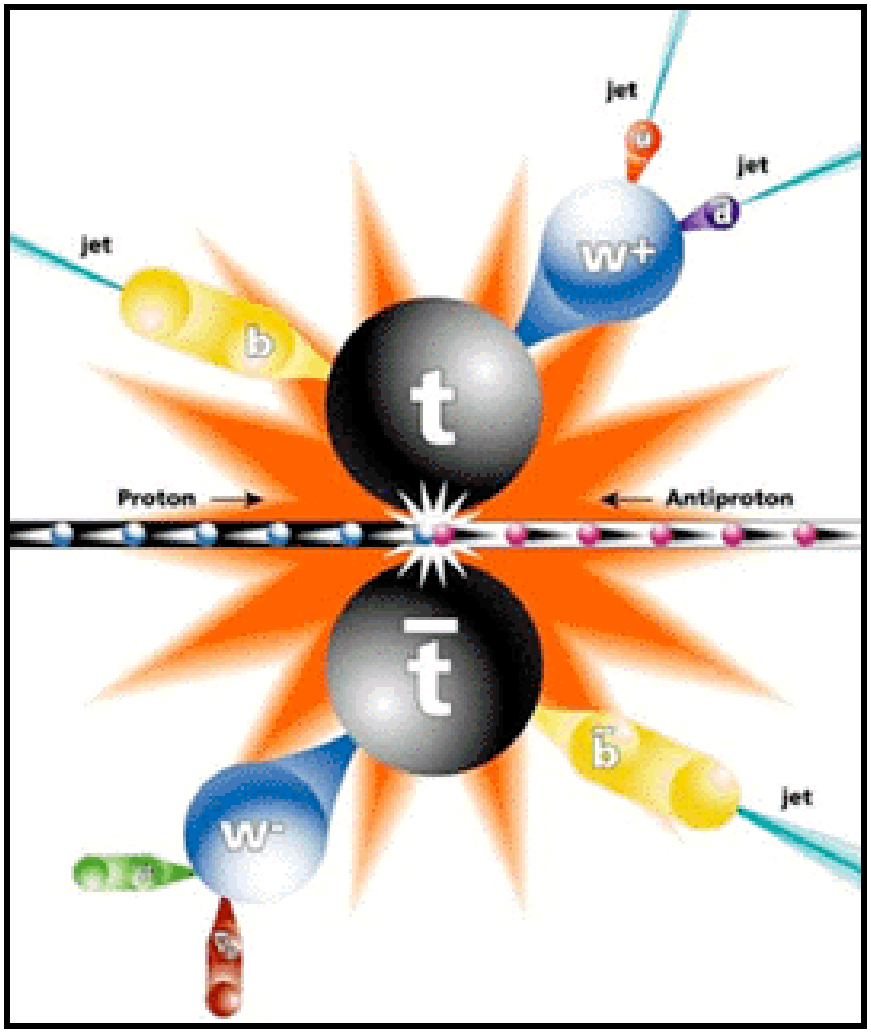
90% $q\bar{q}$ 10% gg at Tevatron $\sqrt{s} = 1.8\ TeV$

85% $q\bar{q}$ 15% gg at Tevatron $\sqrt{s} = 1.96\ TeV$

10% $q\bar{q}$ 90% gg at LHC $\sqrt{s} = 14\ TeV$

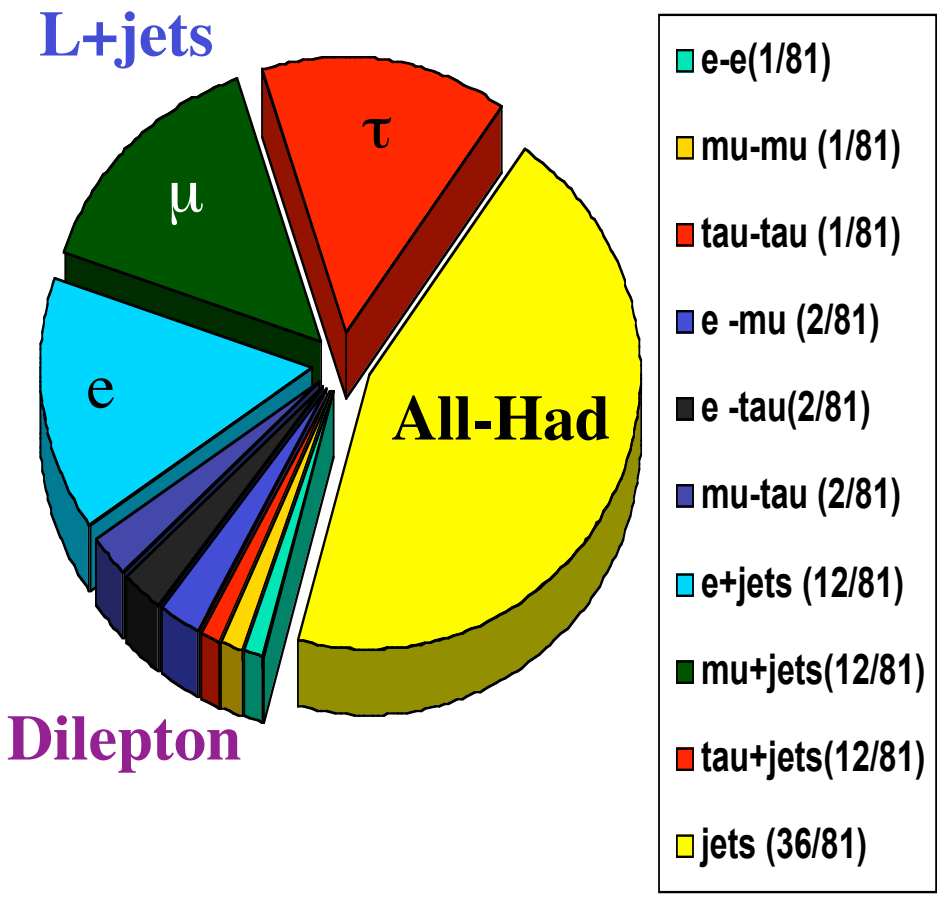
- Top decays t->Wb ~100%
- Top lifetime ~ 4×10^{-25} sec
  - Doesn't hadronize
- Decay of W identifies channel
  - Dilepton, L+jets, All-hadronic

(See Shapiro and Womersley talks for more on top decays)



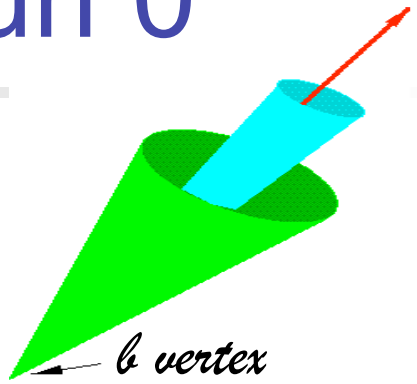
Top Decay Channels

- **Dilepton**
  - Few events but pure
  - final state: lν lν **bb**
- **Lepton + Jets**
  - More events, less pure
    - Add b-tags
  - final state: lν qq **bb**
- All-Hadronic
  - Lots of events, huge QCD bkg
  - final state: qq qq **bb**
  - Not used in discovery



Looking for Top in Run 0

- Believe $M_{Top} < M_W$
  - Decay mode would be W -> tb with t -> blν
- Search strategies
  - Dilepton channel
    - ee, eμ, and μμ
  - L+jets channel
    - Added **SLT** tags
- Set limit $M_{Top} > 91$ GeV
- **CDF had no silicon yet!**

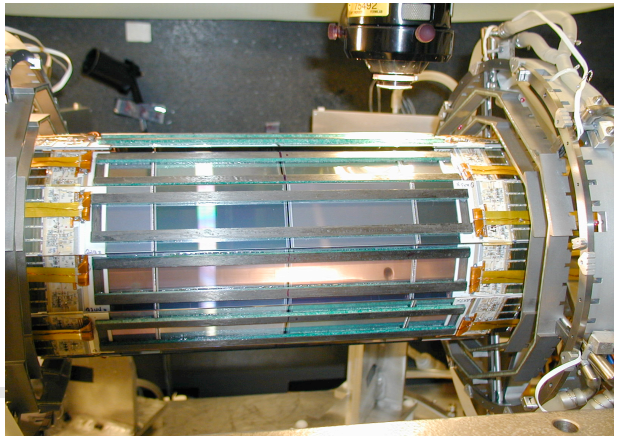


- Soft Lepton Tagging
- Identify semileptonic B decay

$$b \to \ell \ , \ b \to c \to \ell$$

- ε(SLT) ~ 20%

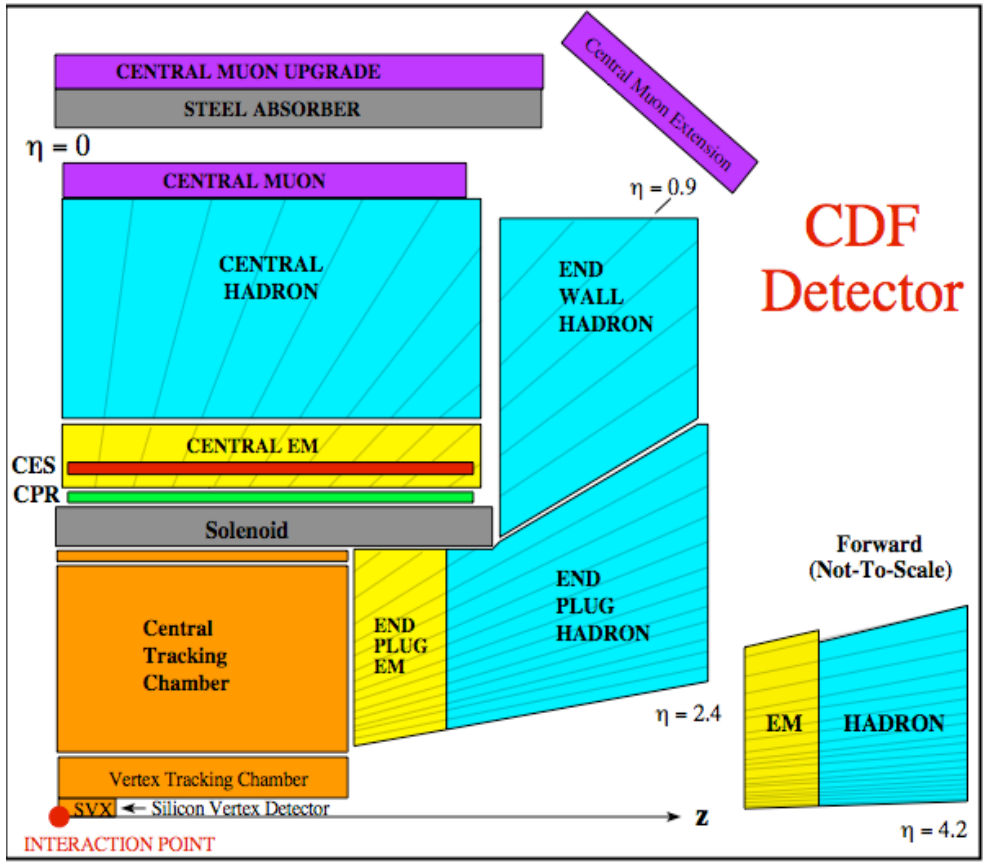
Building the Silicon VertexX Detector



- Silicon used at fixed target to measure particle lifetimes and tag particles
- Not easy to sell idea to CDF
  - Hadron environment too messy to do precision tracking and heavy flavor physics (b and c)
  - No obvious physics case for device
    - Top discovery not a factor, didn't consider b-tagging
  - Many technical challenges with construction and readout in collider environment
- Dedication by Pisa (especially Aldo Menzione) and LBL groups got detector built

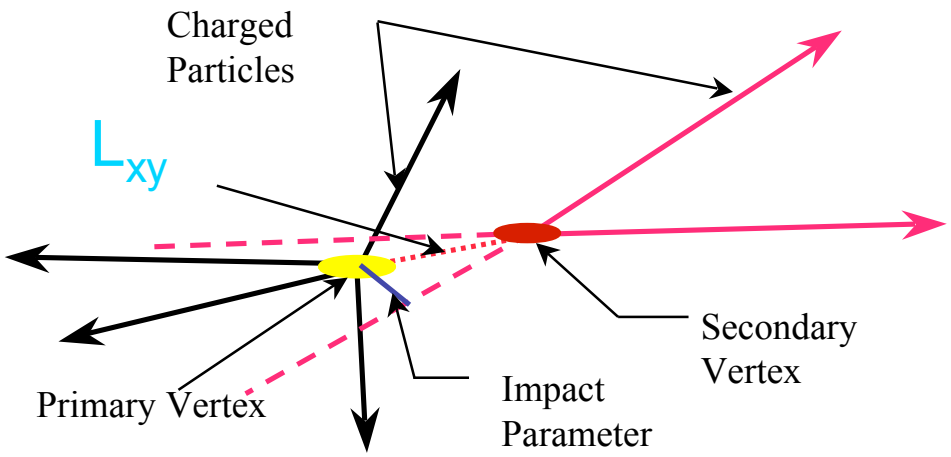
Fermilab Gets Serious Run Ia

- June ‘92 - May ‘93
- CDF now has SVX and muon upgrades
- D0 is taking data
- Developing strategies for discovering top
  - Counting experiments
  - Kinematic analyses



b-tagging using Secondary Vertices

- Use new SVX and b lifetime
  - $c\tau$ ~ 450mm
  - b hadrons travel L_{xy} ~ 3 mm before decay
- Run 1a had 3 SVX taggers
  - **Jetvtx** - ≥2 tracks form secondary vertex with $|Lxy|/\sigma_{Lxy} \geq 3$
  - **Jet Probability** - use track impact parameter, probability of track consistent with primary vertex
  - **d-ϕ -** Uses impact parameter, d, and azimuthal angle,ϕ, of tracks



- See Dominguez talk on tracking and b-tagging
- Secondary VertexX Tagging
- ε(SVX) ~ 50%

Silicon Vertex Detectors Work (in a hadron collider)!

e + 4 jet event

40758_44414

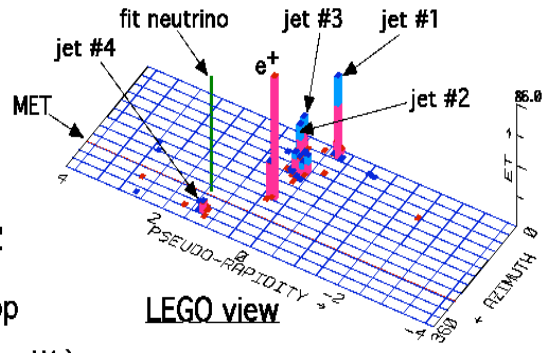
24-September, 1992

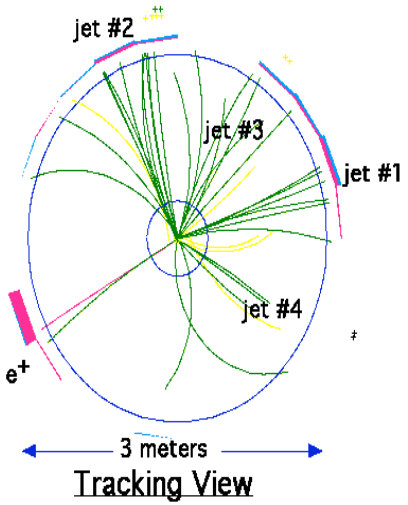
TWO jets tagged by SVX

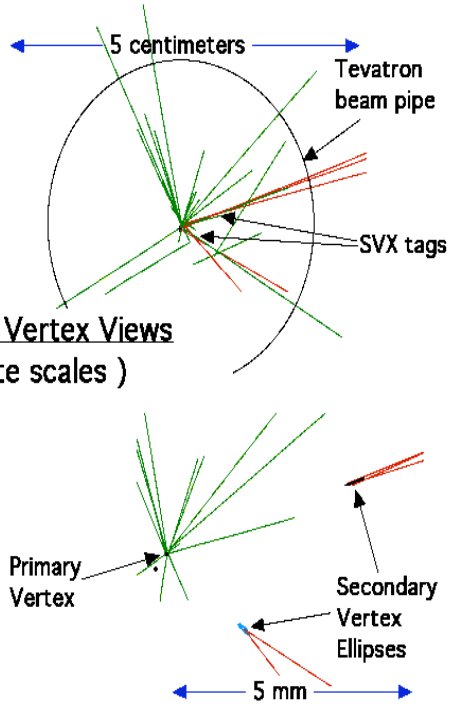
fit top mass is 175±10 GeV/c^2

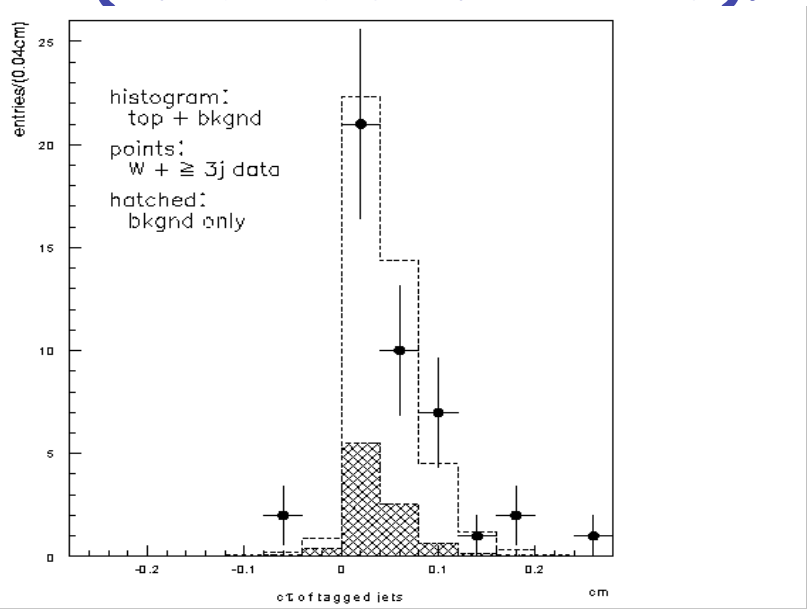
e^+, Missing E_t, jet #4 from top

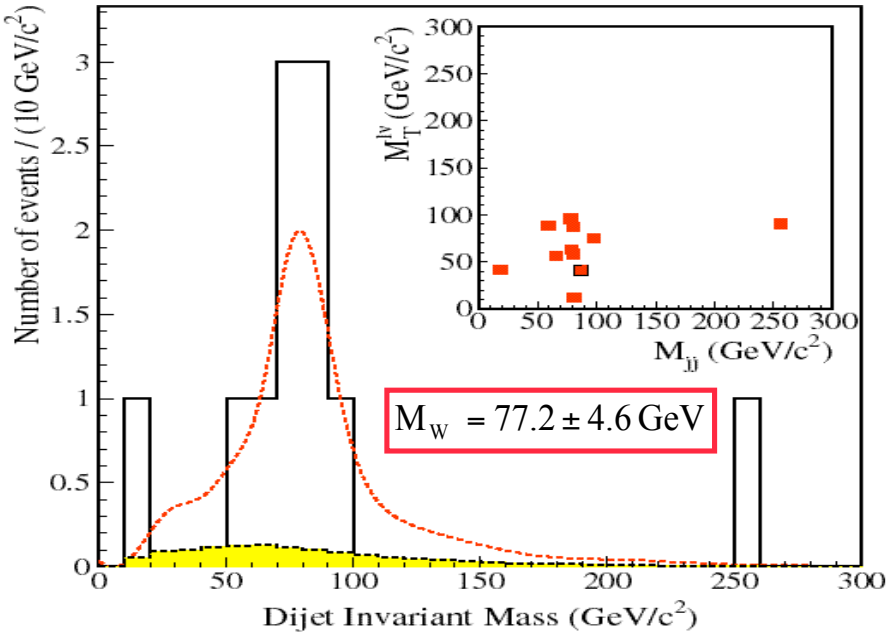
jets 1,2,3 from top (2&3 from W)





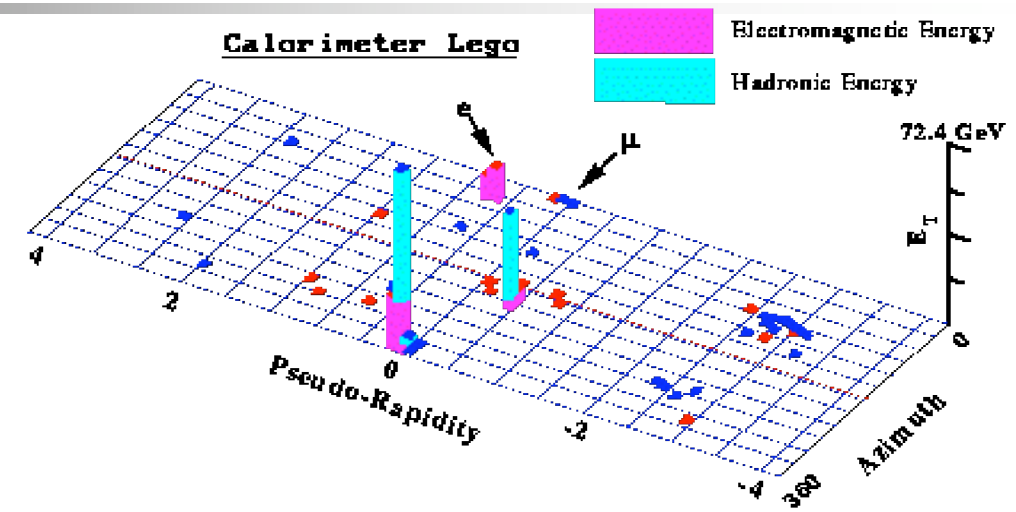


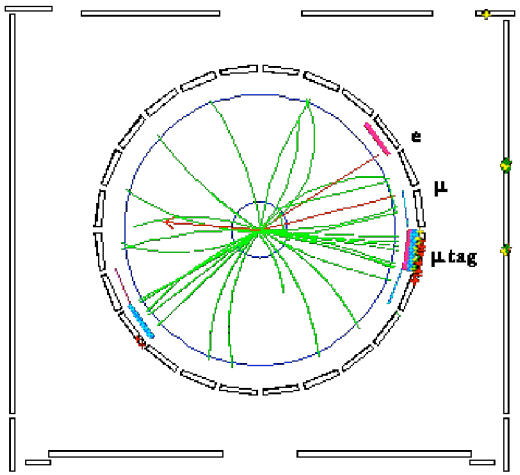


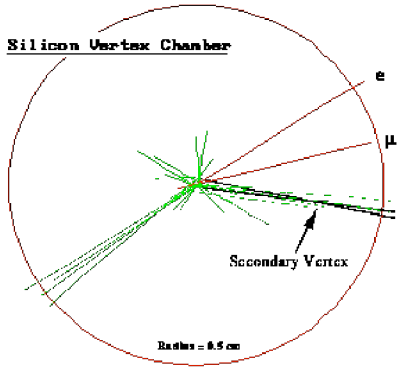


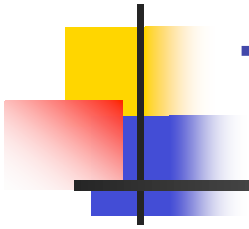
The Golden Event

- DPF event
  - Oct. 22, 1992
  - eμ + 2 jet event
    - 1 jet tagged by both SLT and SVX
  - Decide not to declare discovery on 1 event
    - D0 similar experience
- **Push for top is on!**









The “Evidence” Paper

- July 1993 - CDF collaboration meeting
  - Seeing excess in all channels
  - Decide to write 4 PRLs
- Oct. ‘93 - CDF collab meeting
  - Reject PRLs and opt for giant PRD
- Jan. ‘94 - CDF collab meeting
  - Many questions and concerns (next slide)
- April 26, 1994 - Submit “Evidence for Top Quark Production” - PRD 50, p.2966-3026

Comments on “Evidence”

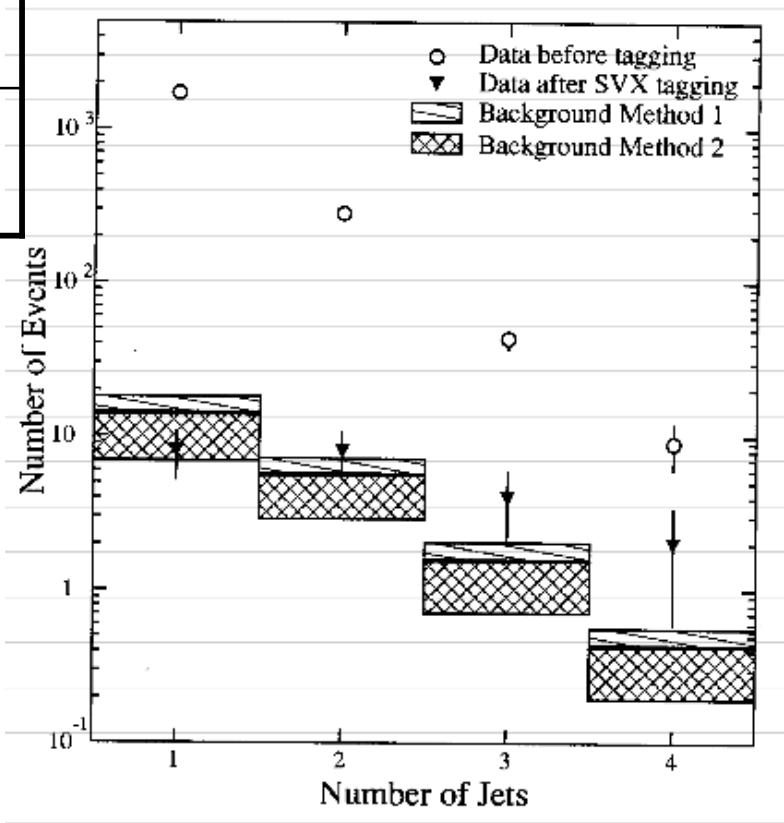
- 9 months of endless meetings answering questions while attempting to keep results quiet
- Some of the concerns raised:
  - Choice of official SVX b-tagger
    - Tuning on data
  - Method 1 vs. Method 2 background
    - Overestimate from data or trust MC
  - Role of kinematic analyses
    - Supporting evidence but not in significance
  - Calculate significance
    - Events or tags, weight of double tags

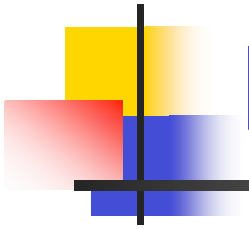
Results for Evidence Paper

Channel:	SVX	SLT	Dilepton
Expected Bkg.	2.3±0.3	3.1±0.3	0.56±0.25
Observed Events	6	7	2

- Combining all channels with 19 pb^{-1}
- Prob bkg fluctuate up to observed = 0.26% (2.8σ)

(See Lyons talk on stat.)





Run Ib and Observation

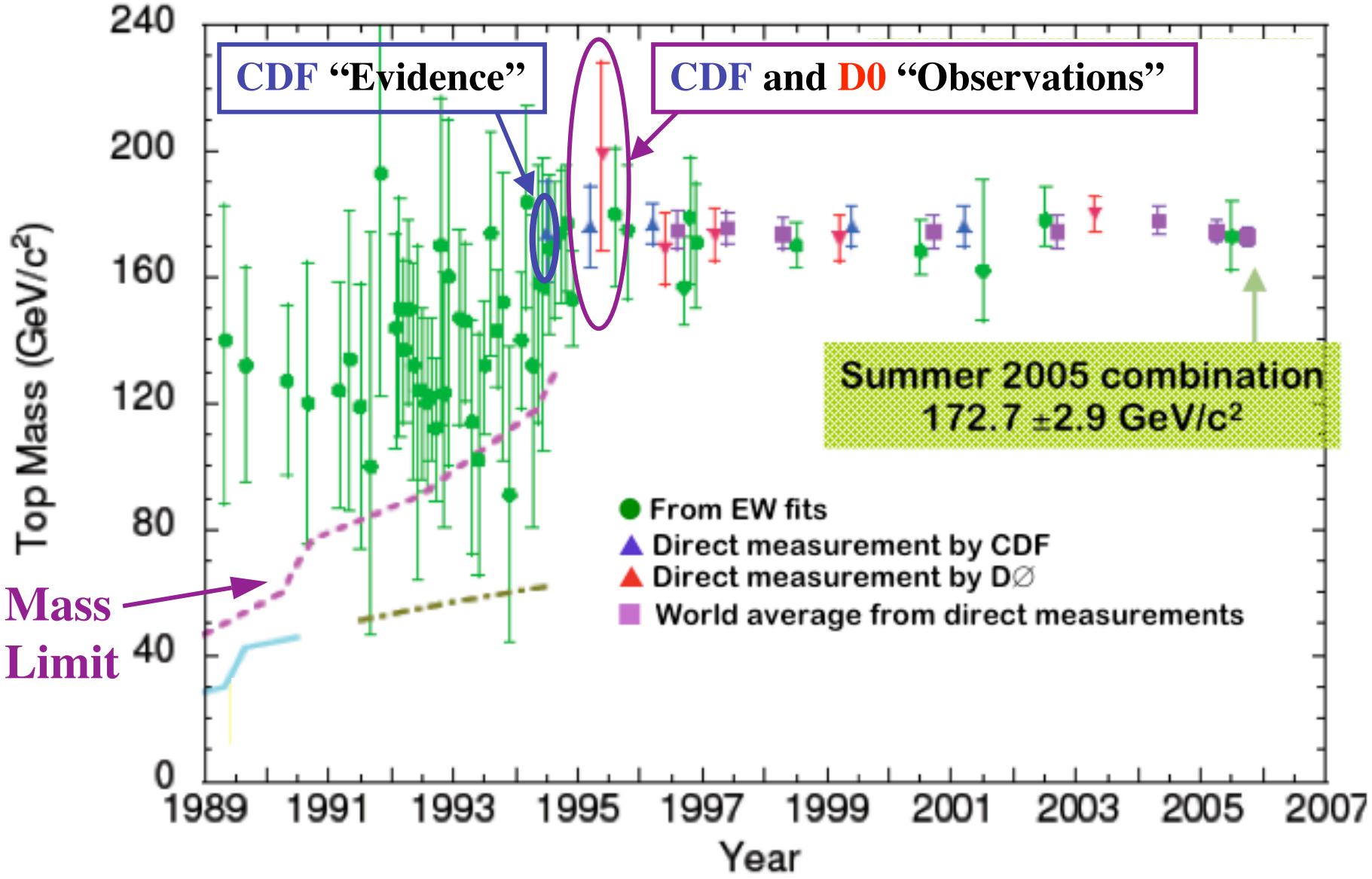
- Run Ib Feb. ‘94 - Dec. ‘95
  - New rad-hard silicon - SVX’
  - Optimized SVX b-tagger - Secvtx
- Jan ‘95 - CDF collaboration meeting
  - See significant excess in all channels
  - Slight changes to Evidence analyses
    - One optimized SVX b-tagger - Secvtx
    - Use Method 2 background (smaller # of bkg events)
- March ‘95 - D0 and CDF submit PRL’s

Top Discovery

Channel	SVX	SLT	Dilepton
Observed	27 tags	23 tags	6 events
Exp. bkg	6.7±2.1	15.4±2.0	1.3±0.3
Probability	2×10^{-5}	6×10^{-2}	3×10^{-3}

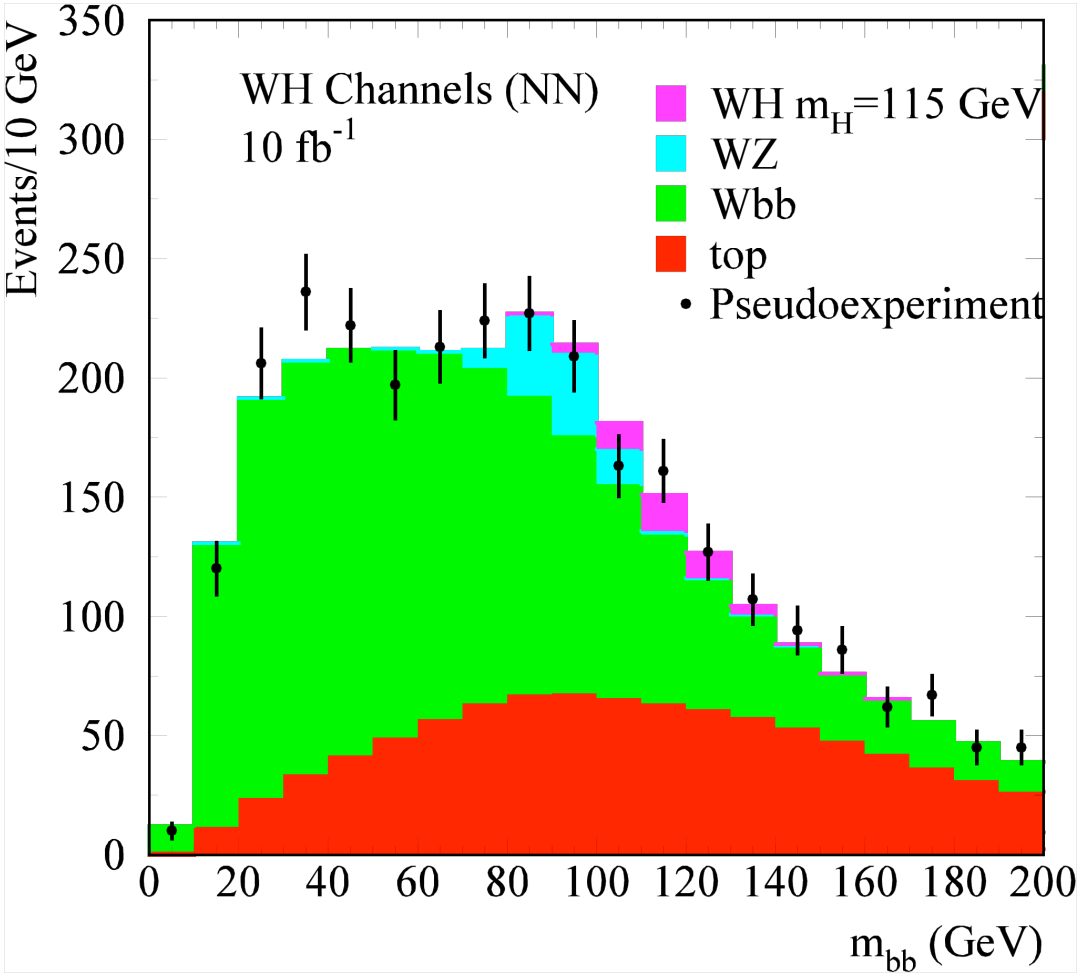
- Using 67 pb-1 (includes Evidence data) combined Prob = 1×10^{-6} (4.8σ)
- If include mass distribution Prob = 3.7×10^{-7} (5.0σ)

Top Mass vs. Year



Yesterday's sensation is today's calibration and tomorrow's background.
- Feynman

- Calibration sample
  - Just like we used Ws, Zs
    - Jet Energy Scale
    - B-tagging
- Background
  - Higgs



Books on HEP Discoveries

- **Nobel Dreams** by Gary Taubes
  - Discovery of the W,Z bosons and Carlo Rubbia's group
- **The Evidence for the Top Quark** by Kent Staley
  - Philosophy discussion of discovery in science but most of the book looks at CDF's process for the Evidence and Observation papers